REPORT 47

SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMELIORATION

DU MILIEU PEDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

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TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

EFFECT OF WOODLOT BORDERS AND CROP RESIDUE ON THE DISTRIBUTION OF INVERTEBRATES IN AGROECOSYSTEMS

FINAL REPORT

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Executive Summary

EFFECT OF WOODLOT BORDERS AND CROP RESIDUE ON THE DISTRIBUTION OF INVERTEBRATES IN AGROECOSYSTEMS

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This study examined the relationships among distance from woodlots in agricultural fields, crop residue, and the abundance and diversity of soil invertebrates. Two sites were used in Southern Ontario. Each site had one field with crop residue over the winter of 1990, and one field without crop residue. Populations of cryptozoic (soil surface) fauna, foliage fauna, and earthworms were measured.

The abundance and richness of cryptozoic invertebrates declined significantly with increasing distance into the fields. The decline in abundance was dependent on date, the greatest decline with increasing distance into the field was in late fall. These declines suggest that cryptozoic invertebrates were present at distances further out into the field, despite their comprising few taxa, and that many of the invertebrates are dependent on the woodlots for winter shelter. Crop residue on the field over winter significantly increased cryptozoic abundance and richness at all distances from the woodlot in some fields, suggesting that crop residue promoted invertebrate persistence in these fields.

The numbers and richness of Carabidae (carabid beetles) increased significantly with increasing distance into the fields in late July and

August, particularly in the corn cropping systems. The crop residue appeared to have little effect on carabid distribution.

Eveness of the cryptozoic community increased significantly with increasing distance into the fields. Species dominance, therefore appears greater in the woodlot than in the field. Crop residue cover on some fields significantly decreased eveness at all distances from the woodlot.

Earthworm number and mass increased significantly with increasing distance into the fields, possibly because of increased competition from other macro-decomposers which were more abundant near the woodlot.

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Introduction

Windbreaks, including shelterbelts, woodlots, fencerows, and hedgerows, tend to increase yields of adjacent field and forage crops through reduced wind erosion, improved microclimate, snow retention, and reduced wind damage (Kort, 1988). Shelterbelts are also attractive to insects and other invertebrates. Small or wingless insects often depend on wind for transport and often settle in protected windbreaks. Insects also accumulate in these areas because of reduced windspeeds which give greater control over flight (Pasek, 1988).

Many invertebrates overwinter in these sheltered sites (Nazzi et al., 1989). Early spring growth in hedgerows and woodlots attracts the invertebrates in May and June before many arable crops are well established (Pollard, 1971). It is therefore conceivable that invertebrate abundance decreases with increasing distance from a woodlot. Shelterbelts and woodlots provide suitable overwintering sites for many invertebrates because the dense vegetation, deep sod layer, and thick litter layer dampen temperature fluctuations and provide insulation against low winter temperatures (D'Hulster and Desender, 1984). Soils are often less dense in non-agricultural areas, providing better aeration for overwintering animals (D'Hulster and Desender, 1982). In addition, invertebrates are not disturbed by agricultural management in these sites, which promotes their persistence. Crop and hay fields are often less suitable for some organisms to overwinter in because of the physical disturbance of yearly plowing and/or a more poorly developed sod layer (D'Hulster and Desender, 1984).

In the spring, some invertebrates move from wooded vegetation into the surrounding fields where prey is abundant. In Western Europe, some carabid

species overwinter in shelterbelts and spread into the field as far as the influence of the microclimate of the trees extends. One carabid beetle, Agonum dorsale, leaves its winter quarters in March-April, migrates to the fields in May, returning to a shelterbelt in August, and moves into its winter habitat again in October (Thiele, 1977).

Other invertebrates stay in hedgerows and woodlots longer in the spring, producing an early generation which feeds on early-growing perennial plants. They then move out into the arable crop after it has become established and feed on insects there. Anthocoris nemorum (Heteroptera) is an example of a common predator in Europe with this type of behaviour (Pollard, 1971).

Other studies indicate that, in general, arthropod diversity drops rapidly as one moves away from the edge of a field (Reichert and Lockley, 1984). The declining diversity indicates that these migrating organisms do not effectively recolonize whole fields, probably only moving until suitable habitat is found.

A study of soybean agroecosystems in Italy (Nazzi et al., 1989) found that hedgerows were important in keeping faunal equilibrium by maintaining non-excessive dominance, greater diversity among the species and greater diversity for carabid beetles. The structure of carabid and spider communities in open fields appeared less balanced in having greater dominance, and less diversity (Nazzi et al., 1989) than that of the fields surrounded by hedgerows. These authors concluded that hedgerows maintained populations of polyphagous predators which help to control numbers of phytophagous organisms (plant herbivores). Other researchers have found similar results. Florida corn fields surrounded by burned pine forest and weedy fields have a more diverse and abundant predator fauna than corn fields surrounded by annual

crops (Altieri and Whitcomb, 1980). This is believed to occur because increased habitat diversity provides alternate feeding sites for natural predators and this facilitates dispersal into crop systems (Van Emden, 1965; Altieri and Todd, 1981).

Agricultural practices often reduce populations of soil invertebrates. In root crop and cereal fields of northern great Britain, activity indices of carabids have decreased in some fields by more than 95% due to cultivation (Lys and Nentwig, 1991). Undisturbed areas such as hedges or woodlots facilitate dispersal of carabids back into agricultural fields, and lower the risks of local extinctions of these populations, because these uncultivated areas are important hibernation sites, shelters, and an abundant source of food (Lys and Nentwig, 1991).

Many species of arthropods, however, are restricted to specific habitats, and do not freely range throughout agricultural landscapes. For these arthropods, hedges and woodlots might have limited importance, and a decline in abundance and diversity may not be expected as one moves away from a windbreak. Pollard (1971) found that syrphid fly (Syrphidae) predation on aphids was not affected by the presence of hedgerows surrounding test fields, and concluded that diversity of habitat outside a crop does not add to the stability of crop pest populations. Pollard (1971) indicated that many of the predators found in crops are permanent members of the crop fauna and are not influenced much by hedge or woodlot diversity. These results were in agreement with those of Thiele (1977) who found that most carabid beetles were very habitat specific, rarely moving from one ecosystem to another. Studies on carabids in Sweden (Wallin, 1985) have found that some carabids in agricultural fields are true inhabitants, and are not, or are only slightly

dependent on, adjacent uncultivated habitats during parts of their life cycle. These carabids were often found along field edges, however. Agricultural management does benefit some invertebrates, particularly through improved drainage, irrigation, and fertilizer application (Dangerfield, 1990), and these invertebrates probably prefer to live in fields.

Those invertebrates which do not depend on uncultivated areas for overwintering, often overwinter in crop fields. For example, several carabid species dig down to depths of 30-45 cm to overwinter even in hard clay soil (Thiele, 1977). The success of this type of overwintering depends on the insulative capacity of the soil surface, and therefore might be related to the amount of crop residue on the soil surface. However, this success would vary from species to species. Carabid larvae also overwinter in crop fields, some remaining highly active near the soil surface throughout the winter, while others inhabit deep layers (Thiele, 1977). Absence or presence of litter may have a more profound effect on species which are active near the surface during the winter. Surface litter has been shown to provide increased overwintering habitat for herbivorous insect populations and is assumed for predatory carabid fauna (House and All, 1981).

Earthworms have also been found to be influenced by hedges or woodlots. In a poplar windbreak in Czechoslovakia (Miko et al., 1989), earthworm number was highest on the windward side of the shelterbelt, was low in the windbreak, and rose again as one moved out on the leeward side of the windbreak. Earthworm numbers were found to be correlated with soil humidity, and were low in the windbreak because of high evapotranspiration rates.

Three groups of invertebrates will be examined in the following study with respect to their relationship with woodlots, the cryptozoic

invertebrates, the foliage arthropods, and earthworms. The cryptozoic invertebrates live on the surface of the soil and include staphylinid and carabid beetles, spiders, harvestmen, millipedes, slugs, and sowbugs. These invertebrates are important in pest control (eg. ground beetles, spiders), in residue decomposition (eg. millipedes, sowbugs) and subsequent nutrient release (Hendrix et al., 1989).

The foliage arthropods are found on crop and weed plants, and include parasitic wasps of several families, Syrphid flies, Coccinellidae (ladybird beetles), true bugs (Hemiptera) and many plant herbivores (Pollard, 1971). Some of the foliage invertebrates are important in predation and parasitism (Thiele, 1977; Pollard, 1971).

Earthworm activity has a variety of influences within the soil. Briefly, their activity has been found to influence plant yield (Edwards and Lofty, 1980), soil structure (Shaw and Pawluk, 1986), water infiltration rate (Ehlers, 1975; Lal, 1988; Shipitalo and Protz, 1987), residue breakdown (Zachmann and Linden, 1989; MacKay and Kladivko, 1985), and encourage microbial growth (Ghilarov, 1963; Vimmerstedt and Finney, 1973).

Central Question and Hypothesis

This study addresses two questions. First, does invertebrate abundance and diversity decrease in agricultural fields with increasing distance from woodlots? Second, does crop residue cover on fields have any influence on the distribution of invertebrates with increasing distance from woodlots?

Two null hypotheses will be tested to answer these questions. The first null hypotheses is that increasing distance from a woodlot has no influence on the abundance, richness and eveness of distribution of cryptozoic and foliage

fauna communities. This hypothesis will be tested by determining the slope of the faunal-distance relationship (See Figure 1). A significantly non-zero slope would allow the null hypothesis to be rejected. This hypothesis will be tested using all invertebrates that are sampled, not strictly those that overwinter in uncultivated areas, or those that overwinter in agricultural fields. The results will therefore assess whether the woodlot has any influence on the entire invertebrate community. It is already known that woodlots influence some species' distributions (Thiele, 1977; Reichert and Lockley, 1984).

The second null hypothesis to be tested is that the presence of crop residue on a field has no effect on the abundance, richness and eveness of distribution of cryptozoic and foliage fauna populations. This hypothesis will be tested by comparing abundance and diversity in spring and fall plowed fields, and also in zerotillage fields with and without crop residues. If crop residue influences the invertebrates, the rate of decline (slope) should be lower with increasing distance into the field containing surface residue (See Figure 1). Significantly different slopes would allow this null hypothesis to be rejected. This hypothesis is a test of the influence of crop residue on the entire invertebrate community.

Materials and Methods

1) Selection of the study sites

Two sites were used in this study, and each had two cropping systems, - one with crop residue on the soil surface during the winter, and one without. The first site was located eight kilometers south of Mount Forest, Ontario (Lat. 45° 54' 48", Long. 80° 43' 30"). The soil at this site was a well drained Harriston loam (pH 7.5; Order Luvisols). In 1990, half of the field was in corn, and the other half was in barley with strips of corn in the center of the field (Figure 2). The corn was cut for silage in the fall of 1990, leaving almost no residue on the soil surface. The barley was also harvested, but most of the straw was left behind. There was no tillage in this field in 1990. This left two distinct areas, one with very little residue, and one with a thick straw residue cover. In 1991, the whole field was lightly harrowed, and planted with corn. The two cropping systems here are: barley-residue corn, and no-residue corn, respectively. Four, 50 m transects were set up in each of the two cropping systems. The entire field at this site was surrounded by a woodlot dominated by Eastern white cedar (Thuja occidentalis), Sugar maple (Acer saccharum), Choke cherry (Prunus virginiana), and Trembling aspen (Populus tremuloides). The two cropping systems within this field had identical slope and drainage patterns.

The second site was located eight kilometers southeast of Fergus, Ontario (Lat. 43° 43' 20", Long. 80° 17' 00"). This site comprises two adjacent fields, both of which were planted with soybeans in 1990. The soil type of these fields was an eroded phase Fox sand, and an eroded phase Brady sandy loam; both are in the same catena, the latter is more poorly drained (Order Luvisols). After harvest in 1990, one field (Fox sand) was chisel

plowed, burying almost all of the crop residue. The second field (Brady sandy loam) was not plowed, leaving a thick cover of soybean residue on the surface. The cropping systems here were fall-plowed soybeans, and spring-plowed soybeans, respectively. In the spring of 1990, the field with no crop residue was harrowed with tandem disks, and the field containing crop residue was chisel plowed and harrowed similarily. Five, 50 m transects were run into these two fields from nearby woodlots. These woodlots bordered these fields over 250-300 m, and were dominated by Sugar maple (Acer saccharum), Trembling aspen (Populus tremuloides), and Beech (Fagus grandifolia).

Both study sites therefore have one field which had crop residue on the soil surface during the winter of 1990, and one field without crop residue during this period. There are four tests of the first null hypothesis, and two tests of the second null hypothesis, one for each site.

2) Invertebrate sampling procedure

Sampling for invertebrates was done from mid-July until late October. This period was chosen to miss the early season migrations and trap the spatial distribution that is most common at the late summer- early fall peak of invertebrate activity (Neave, 1992; Wallin, 1985).

The following definitions are used in this study:
Abundance is the total number of individuals found in a sample. **Richness** is the number of taxa found in a sample, and **Occurrence** is the number of taxa found in all samples. Eveness is the equitability of distribution of abundance among the taxa (Hill, 1973). A community whose abundance is 100, and richness is 4, is more even when each taxa has 25 individuals, than when

one taxa has 97 individuals, and the other three taxa have one individual. The latter community is said to have greater dominance.

a) Pitfall traps

Pitfall traps are behavioural traps that capture cryptozoic invertebrates. At each transect, pitfall traps were placed in the soil 7.5 m into the woodlot, at the woodlot edge, and 7.5m, 15m, 30m, and 50m into the field. The pitfall traps were made with 12 cm clear plastic containers, and were partially covered with a lid. Any invertebrates whose path crosses the pitfall traps fall in and are preserved by ethylene glycol. Pitfall traps were emptied weekly, and the invertebrates were then identified and counted.

During the sampling season, some pitfall traps were emptied by raccoons (Procyon lotor). Quinine was added to the ethylene glycol to deter raccoons, but this had no effect. The use of only water in the pitfall traps did not deter racoon interest, either. A number of samples were lost in this way, and the pitfall trap samples over a two week period had to be combined to make a complete set of samples. As a result, only five complete sets of samples were obtained at the Mount Forest and Fergus sites. These pooled sample dates were: August 2nd-9th, August 16-22, August 30-September 6th, September 13-27, and October 8th-16th, and are referred to as sample dates 1 through 5, respectively.

b) Foliage arthropods traps

Foliage arthropods were sampled using two methods. The first method involved taking a large (40 x 80 cm) plastic bag, placing it rapidly over five soybean plants, cutting the stems of the plants at their base, and sealing the bags with the plants inside. This procedure was done in both soybean fields at 0, 20 and 40 m away from the woodlots. These sealed bags were then frozen.

After freezing, the plants were beaten within the bags to dislodge any invertebrates, the soybean plants removed, and the contents of the bag were then examined. Samples were also placed in Tullgren funnels (Southwood, 1987), instead of freezing them, to see if more invertebrates could be obtained. The plastic bag method was used to sample arthropods on soybeans every two weeks.

The second method of sampling foliage arthropods was to use an intercept trap (Southwood, 1978). The corners of a large (50 x 100 cm) yellow plastic bag were tied to adjacent corn plants, and a plastic tray 1m wide was suspended below and filled with ethylene glycol. Flying invertebrates were attracted to the yellow material, flew into it, and subsequently fell into the tray of preservative (Southwood, 1987). These traps were set up along the corn field transects, at 0, 20, and 40 m from the woodlot, and were emptied weekly. Raccoons destroyed most of these traps every week they were set out. Too few samples were obtained to run a statistical analysis.

c) Earthworms

Earthworms were sampled using a combination of the formalin and hand sorting methods. Earthworm samples were taken at 0, 25, and 50 m at each transect. Formalin (25 mL) was added to 4.5 L of water and sprinkled over 0.45 square meters (Raw, 1959). Any earthworms that came to the surface were collected and, after 30 min., the soil was excavated to a depth of 20 cm, and the rest of the earthworms were found by hand sorting. Sampling for earthworms was done from October 15-18th, 1991, in barley-residue and no-residue corn, and in spring plowed soybeans. Fall-plowed soybeans were not sampled because of lack of access to the site by vehicle.

3) Physical measurements

Soil water content was measured gravimetrically over 0-10cm depth at the same distances from the woodlots as the pitfall traps. Water content was measured in both corn, and the spring-plowed soybean cropping systems. Differences in residue cover between fields was estimated using 0.06 m^2 quadrats on May 28th, 1991.

4) Statistical analyses

Pitfall trap, earthworm, and water content results were run through an analysis of variance factorial model, which considered all interactions between factors. This model was simplified by removing non-significant factors and interactions, and then testing contrasting slopes and intercepts of the distance-abundance/diversity relationship in different cropping systems. Whether slopes were significantly different from zero was tested using a t-test, with an accepted probability of a type I error of 5%. Intercepts and slopes of different cropping systems were contrasted using t-tests.

Results are presented in the form of intercepts and slopes of the invertebrate abundance/diversity - distance relationship. Cryptozoic invertebrate abundance and number of carabids were log(e) transformed, because the abundance data were not normally distributed and could not be used in the factorial model without transformation.

The results presented are from the ANOVA factorial model. If slopes were not significantly different among the different cropping systems (ie. no interaction between distance and cropping system), the model used all data to create a common slope. As a result, cropping systems in some figures

demonstrate common, identical slopes. This precludes showing the small variations in slope interest in the untransformed results.

Results

1) Analysis of invertebrate distribution

a) Invertebrates in pitfall traps

A large number of taxa was captured in the pitfall traps (Table 1). The dominant taxa captured were carabids and crickets for the first two sampling periods, and Anthomyiid flies, harvestmen, and ants were dominant throughout the sampling season. Staphylinid beetles, slugs, and sowbugs were common in the pitfall traps. Occurrence was usually greater when distances were less than 8m from the woodlot for all cropping systems (Tables 1 and 2), particularly at the earliest sample date.

Both slugs and millipedes (Blanilius spp. and Scytonotus spp.) were concentrated near the woodlot (Tables 1 and 2). These animals were found at distances beyond 8m at the last sample date, as a few had moved out to 15m by the end of the growing season. These animals did not advance to 30 and 50m from the woodlot.

There was a general decrease in abundance of cryptozoic invertebrates with increase in distance from the woodlots (Figure 3). The relationship between the abundance of the cryptozoic community and the distance in a field from a woodlot had both linear and quadratic components. There was no significant interaction between distance and cropping system, indicating that the slope of the abundance-distance relationship was not significantly different between cropping systems. The model, therefore, used the data points from all fields to calculate a common slope. There was a significant ($p<0.05$) distance by date interaction, and the slopes were different for the five sample dates. The slopes revealed a trend towards an increase in the rate of decline of abundance as the season progressed (Figure 3). The slope of

this relationship (all cropping systems) on the first sample date was: Slope = (dist.) X (-0.02925) - (dist.) X 0.000515, and the slope on the fifth sample date was: Slope = (dist.) X (-0.06466) + (dist.) X 0.000515, both being significantly different from zero.

The abundance intercepts were different in each cropping system (Table 3). The spring-plowed soybean cropping system had the largest intercept, which also was significantly higher than the intercept in fall-plowed soybeans (t-test, $p<0.0001$). The intercepts in barley-residue corn, and no-residue corn were not significantly different.

Carabid beetles were sufficiently abundant in the first two sampling dates to analyze their slope and intercepts. There was no significant interaction between distance and date in the factorial model of carabid abundance or richness, so slope did not change with date. There was, however, a significant ($p<0.05$) distance and cropping system interaction for both carabid abundance and richness, and the slope was different for each cropping system (Figures 4 and 5).

The rate of increase of number and richness of carabids was greatest in the corn cropping systems (Figure 4 and 5). Slopes were not significantly different when comparing barley residue and no-residue corn systems, or fall and spring-plowed soybeans. All slopes were significantly ($p<0.05$) different from zero.

Intercepts of carabid abundance and richness were not significantly different when comparing barley residue and no-residue corn, and fall and spring-plowing soybeans (Table 3).

There was a linear decline in richness of the cryptozoic community with increasing distance into the fields (Figure 6). There were no significant

interactions between distance and cropping system, or distance and sample date in the factorial model, so the slope was the same for all cropping systems and dates. The slope of this decline in all cropping systems was: Slope = (dist.) X (-0.03466), and was significantly different from zero.

The richness intercepts were different in each cropping system (Table 3). The intercept of spring-plowed soybeans was significantly higher than the intercept of fall-plowed soybeans (t-test, $p<0.004$). The intercept of barley residue corn, and no-residue corn was not statistically different.

The general trend of the relationship between eveness and distance from a woodlot was an increase in eveness with increasing distance into the fields (Figure 7). The slope of the relationship between eveness of the cryptozoic community, and the distance from a woodlot had both linear and quadratic components, and is given as: Slope = (dist.) X 0.003244 - (dist.) X 0.000034. This slope was the same in all four cropping systems and all five sample dates, and was significantly different from zero. The increase in eveness became smaller with increasing distance into the field, and, presumably, reached a maximum, and begin to decline at some point greater than 50m from the woodlot.

The eveness intercepts were different in each cropping system (Table 3). The intercepts of spring-plowed and fall-plowed soybeans were significantly different (t-test, $p<0.001$), fall-plowed soil having a more even community. There was no significant difference in the intercepts of barley residue, and no-residue corn systems.

b) Foliage arthropods

Too few samples of foliage arthropods were obtained from any of the traps for statistical analysis. The plastic bag method was used four times on soybean plants. No invertebrates were found in the vegetation samples, whether the samples were frozen and examined, or placed in Tullgren funnels.

The intercept traps set up in the corn cropping systems did capture invertebrates. Occurrence in the barley residue corn system was 20 taxa, in a limited number of samples (Table 4).

c) Earthworms

The number of earthworms increased with increasing distance into the fields (Figure 8). There was no significant distance by cropping system interaction so the slope is the same for all three cropping systems. The slope of the relationship between number of earthworms and distance from woodlots had both linear and quadratic terms: Slope = (dist.) X 0.727 - (dist.) X 0.00916, and was significantly different from zero.

Earthworm number intercepts were different in the three cropping systems, no-residue corn being the highest, and significantly higher than in the barley residue corn system (t-test, $p<0.0001$; Table 3).

The total mass of earthworms also increased with increasing distance into the fields (Figure 9). As there was no significant interaction between distance and cropping system in the factorial model, the slope was the same for all cropping systems: Slope = (dist.) X 0.3032, and was significantly different from zero.

Earthworm mass intercepts were different for the cropping systems, no-residue corn again having the largest intercept, and was significantly larger than that of the barley residue corn (t-test, $p<0.032$; Table 1).

2) Physical measurements

Water content declined with increasing distance from the woodlot in the no-residue corn soil (t-test, $p<0.05$; Table 5). There was no significant decline in water content in the barley residue corn system, or in the spring-plowed soybean fields.

Crop residue cover was significantly higher in the barley residue corn field than in the no-residue field (43.5 ± 8.0% and 16.8 ± 3.4%, respectively) (t-test, $p<0.001$). The crop residue cover was significantly higher in the spring-plowed, soybean field than the fall-plowed field (62.9 ± 12.3% and 7.0 ± 8.1%, respectively, $p<0.001$).

Discussion

Analysis of invertebrate distribution

a) Invertebrates in pitfall traps

Comparison of the occurrence of cryptozoic invertebrates at different distances from the woodlots, and at different times of the year, provides some insight into which invertebrates were migrating, and which appeared to be staying in the fields to overwinter.

On the first sample date, sowbugs, crickets, Staphylinid beetles, Nitidulid beetles, ground beetles, Coccinellid beetles, Anthomyiid flies, ants, Braconid parasitic wasps, wolf spiders, and harvestmen were common, and also present at distances <8m and >8m from the woodlot (Table 1). Slugs, land snails, Blanilius and ground beetles were also common at distances <8m from the woodlot (Table 1).

The above pattern of occurrence changed by the last sample date (Table 2). At this time, ground beetle E was not found at all, ground beetle A and the Coccinellid beetles had left the corn cropping systems, and the Nitidulid beetles and wolf spiders had disappeared from several cropping systems. This change suggests that these taxa had migrated into the woodlots (Thiele, 1977). Crickets, staphylinid beetles, ground beetle B, Anthomyiid flies, ants, Braconid wasps, and harvestmen remained common at all distances from the woodlot at the last sample date. With the exception of the highly mobile Anthomyiid flies, these animals appeared to be staying in the fields, possibly to survive by overwintering.

There was a significant decrease (negative slope) in cryptozoic abundance with increasing distance into the fields. The first null hypothesis (the slope was not significantly different from zero) can therefore be

rejected for cryptozoic abundance. The steepness of this decrease in abundance, depended on the sample date (Figure 3). On the first sample date, there was a decrease in abundance with increasing distance into the field, but the rate of decrease was low, and actually became a rate of increase at 30 m, according to the model. By the last sample date, the rate of decrease in cryptozoic abundance with increasing distance into the fields was much higher. This change in rate of decrease of abundance over time probably reflected invertebrate behaviour. In the summer, the cryptozoic invertebrates appeared to be spread over the entire sampling area as there is little decrease in number with distance. In the fall, when many cryptozoic invertebrates are moving back to the woodlot, the rate of decrease of abundance became much higher as the invertebrates were leaving the field, and migrating into the woodlot and its border.

Crop residue also influenced the distance-abundance relationship. The abundance intercept (Table 3) of spring-plowed soybean fields was significantly higher than that of fall-plowed soybean fields, but the slopes were the same. The second null hypothesis therefore cannot be rejected for invertebrate abundance, but crop residue does have an effect. The rates of decrease are the same for the same date, but the magnitude of the decrease is not, because abundance in the spring-plowed soil is significantly higher than the abundance in fall-plowed soils. There are more invertebrates at every distance from the woodlot in the spring-plowed soil. This difference can be attributed to the presence of crop residue, as it offers protection that is unavailable in plowed soil. There was no significant difference in the intercepts of barley-residue corn and no-residue corn (Table 1). It is not

known whether this difference in residue effect between sites is due to the different residue types, or to other differences between sites.

The abundance of cryptozoic invertebrates is often reported to be lower in fields than in unmanaged habitats (Dangerfield, 1990; Mayes and Price, 1978). This trend was also observed in the present study, although the trend was dependent on date.

The abundance results suggest three conclusions. The first is that there appears to be some invertebrates at greater distances into the field for at least part of the year. This conclusion is supported by the gradual decline of abundance with distance in July and August (Figure 3). The second conclusion is that the woodlots appear to be important shelters for the cryptozoic invertebrates. This conclusion is supported by the decrease in invertebrates active at greater distances into the field in late September and October, and no decrease in activity in the woodlot, indicative of migration to the woodlot. The third conclusion is that crop residue promotes the persistence of invertebrates at all distances from the woodlot. More cryptozoic invertebrates were staying in the field later into the season. This conclusion was supported by the significantly greater abundance at all distances and dates in the spring-plowed soybeans, compared to the fall-plowed soybeans. However, this conclusion did not apply in the corn cropping systems.

Both number of carabids, and richness of carabids increased significantly with increasing distance from the woodlot, so the first null hypothesis can be rejected. The presence of crop residue appears to have little effect on carabid numbers and richness, as slopes and intercepts were

not significantly different when comparing like cropping systems (Table 3). The second null hypothesis therefore cannot be rejected.

Nazzi et al. (1989) also captured more carabids in an agricultural field than in and near a hedgerow. The present study, and Nazzi's, suggest that carabids are successful in dispersing into the agro-ecosytem. In the present study, the analysis of carabid distribution was done at the peak of carabid activity (Nazzi et al., 1989; Thiele, 1977), and not later in the season. It is likely that this distribution would change over the season, as it has been found (Nazzi et al., 1989; Thiele, 1977) that many carabids are dependent on woodlots for overwintering.

There was also a significant decrease in richness with increasing distance from a woodlot (Figure 4), so the first null hypothesis can be rejected for richness as well. This significant rate of decrease is unaffected by date, so the lower richness further out in the field would appear to be permanent. The greater abundance at 50 m in the summer, rather than in the fall, would appear to be due to an increase in the numbers of taxa which are already present, and not due to migration of different taxa during the season. This conclusion is supported by species richness remaining low throughout the season. The decrease in richness agrees with the previously noted decrease in occurrence (Tables 1 and 2).

There was no difference in the rates of decrease of richness in the different cropping systems, so the second null hypothesis cannot be rejected. However, the intercept of spring-plowing soybeans was significantly higher than the intercept of fall-plowing soybeans, indicating that residue cover resulted in more invertebrate taxa being present further into the field (Table

3). There was no significant difference between the intercepts of barley-residue corn, and no-residue corn.

Nazzi et al. (1989) found that species diversity and Shannon's diversity index (combined richness and eveness) were lower in the field than in the hedgerow, this agreeing with the present study. Nazzi et al. (1989) attributed this difference to the hedgerows' providing shelter to animals which are linked with rarer biotopes, such as lowland woods, or to animals which are disrupted by agricultural activities. This is likely also the case in the present study. Richness is greater in the woodlot because some organisms naturally live there and not in the field (refer to discussion of occurrence), and the woodlot also offers shelter to organisms that do live in the field.

The results on richness suggest two conclusions. The first conclusion is that fewer taxa are found at greater distances into the field at all times of the year. This is supported by the strong linear decline in richness in all cropping systems and on all dates. This conclusion suggests that there may be less migration of different taxa into the woodlots than there was of individuals (abundance). Taxa that are found further into the fields may stay there year round, and taxa that are found in woodlots may also be permanent residents (for example slugs and millipedes). The second conclusion is that crop residue on the field over the winter promoted greater richness at all distances into the soybean field. This suggests that crop residue promotes persistence of cryptozoic invertebrates in the field over the winter.

Eveness of the cryptozoic community did not decline with increasing distance from a woodlot, as did cryptozoic abundance and richness. Instead, eveness had a significant rate of increase with increasing distance from the

woodlot (Figure 5). This indicates that the equitability of distribution is greater in the field, than in the woodlot and at its edge. This result, combined with the described decrease in richness with increasing distance into the fields, suggests that there is greater dominance in and near the woodlot than in the field. Greater dominance was often observed in the woodlot in individual samples which would be largely composed of ants, harvestmen, slugs, and sowbugs.

The second null hypothesis cannot be rejected for eveness, as the slopes for all cropping systems were the same. However, the fall-plowed soybean intercept was significantly higher than the spring-plowed intercept (Table 3), so the fall-plowed soybean cryptozoic community was more evenly distributed at all distances than the spring-plowed community (Figure 5). This suggests that the crop residue promotes the persistence of several dominant taxa, whose presence significantly lowers the eveness value. There was no significant difference between the intercepts of barley-residue corn and no-residue corn. Nazzi et al. (1989) reported that greater dominance was found in soybean fields than in nearby hedgerows in Italy. This disagrees with the results of my study, possibly because of differences in taxa that are native to the fields and woodlots. There is also a considerable difference between Nazzi's 3-4 m deep hedgerow, and the > 30 m deep woodlots examined in this study. In addition, Nazzi et al. (1989) used a different measure of dominance, which might account for the difference with my study.

Dominance is either a result of competitive exclusion, or a result of a taxa specializing on a resource that is widely distributed and abundant (Krebs, 1985). Intuitively, competition and specialization should be greater in the woodlot where invertebrates are present year round, and where there is

not as much change in abundance with time. Animals which specialize on soybeans one year, may find that a different crop has been grown the following year. This specialization on a non-permanent ecosystem component often results in high mortality and has been effectively used to control corn rootworm (Krysan et al., 1986).

Crop residue promoted dominance (lower eveness) in the soybean field. This increase in dominance may be a result of one organism being able to exploit the field habitat in greater numbers when there was crop residue present. This would result in a general increase in richness which was observed (Figure 4) when crop residue was present on the soybean field.

b) Foliage fauna

The plastic bag method of rapidly covering plants to sample foliage arthropods was not effective in my study, although it has been successful in others (Kevan, 1991)[1]. The lack of invertebrates captured may be a result of very few arthropods being present on the plants, or that those arthropods on the plants may have flown or dropped to the ground while the plants were being covered with the bag.

The intercept traps were effective in capturing many taxa. This was confirmed through observation and the few samples which were not destroyed by racoons.

c) Earthworms

Both earthworm number and mass were found to increase significantly with increasing distance from a woodlot (Figures 8 and 9). The first null hypothesis can therefore be rejected. The intercept of earthworm number and

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[1]Kevan, P.G. Department of Environmental Biology, University of Guelph. Personal communication.

mass was significantly higher in no-residue corn than in barley-residue corn, indicating that in this case, barley residue did not increase earthworm abundance.

A similar trend was also observed by Miko et al. (1989), who found that earthworm numbers on the leeward side of a windbreak were low, and numbers increased as you moved out from the windbreak. Miko found that earthworm number was negatively influenced by evapotranspiration, close to the windbreak, and correlated with soil humidity. Evapotranspiration and soil humidity do not appear to be factors in my study, as water content was found to be as high in the windbreak as in the field (Table 3). Low earthworm numbers near the windbreak may be a result of competition from other macro-decomposers, such as slugs and millipedes which were more abundant near the windbreak (Figure 3).

Conclusions

The information obtained for the cryptozoic invertebrates provides some insight into the effect of field size on invertebrate distribution. In mid summer, the factorial model predicts that there should be a good number of cryptozoic invertebrates at distances greater than 50 m from the woodlot, as the model shows very little decline in late July and early August. However, these invertebrates will not be at these distances for long, as many have to return to the woodlot eventually (Figure 3). This shorter presence will lessen the degree to which the cryptozoic invertebrates can perform their functions of predation and decomposition. Crop residue on fields over winter may partially remedy this problem because it increased abundance at all distances on all sample dates.

Richness, however, was never high at the greater distances into the field, as shown by the linear decline of species with increasing distance, at all sample dates. Extrapolating from this trend, one can speculate that eventually, far enough from the woodlot, there would be no taxa present that are dependent on the woodlot. Only taxa that are more strongly linked to the field might be present. The absence of taxa such as millipedes could slow the decomposition process. Crop residue on fields over winter appears to extend the distance at which cryptozoic invertebrates might be found in fields.

The extrapolation of the richness data appears to be supported by the eveness data. Eveness generally increased with increasing distance from the woodlot, but this increase would reach a maximum and begin to decline at some distance greater than 50 m from the woodlot, because of the negative quadratic term in the slope. At larger (than 50 m) distances from the woodlot, eveness may conceivably become low, indicating greater dominance. The richness and

abundance extrapolations also predict greater dominance, with relatively high abundance, and increasingly lower richness with increasing distance from the woodlot.

This study appears to suggest that large fields may have taxa poor centers, with several dominant taxa being present in relatively large numbers for part of the year. This is not an ideal situation, as it probably interferes with the natural predator control of pests, and with decomposition and nutrient cycling. The present study, and others (Nazzi et al., 1989), appears to suggest that smaller fields surrounded by a windbreak, are more likely to take advantage of biotic processes. This would be especially true for lower input agriculture which is more dependent on natural biotic activity.

References

Altieri, M.A., Todd, J.W., 1981. Some influences of vegetational diversity on insect communities of Georgia soybean fields. Protection Ecology 3: 333-338.

Altieri, M.A., Whitcomb, J.H., 1980. Weed manipulation for insect pest management in corn. Environmental Management 4: 483-489.

Borror, D.J., DeLong, D.M., 1964. An introduction to the study of insects. Revised Edition. Holt, Rhinehart and Winston.

Burch, J.B., 1962. How to know the Eastern land snails. Wm. C. Brown Company Publishers.

Crossley, D.A.Jr., Howden, H.F., 1961. Insect relationships in an area contaminated by radioactive wastes. Ecology 42: 302-317.

Dangerfield, J.M., 1990. Abundance, biomass and diversity of soil macrofauna in savanna woodland and associated managed habitats. Pedobiologia 34: 141-150.

D'Hulster, M., Desender, K., 1982. Ecological and faunal studies on Coleoptera in agricultural land. III. Seasonal abundance and hibernation of Staphylinidae in the grassy edge of a pasture. Pedobiologia 23: 403-414.

D'Hulster, M., Desender, K. ,1984. Ecological and faunal studies on Coleoptera in agricultural land. IV. Hibernation of Staphylinidae in agroecosystems. Pedobiologia 26: 65-73.

Edwards, C.A., Lofty, J.R., 1980. Effects of earthworm inoculation upon the root growth of direct drilled cereals. Journal of Applied Ecology 17: 533-543.

Ehlers, W., 1975. Observations on earthworm channels and infiltration on tilled and untilled loess soil. Soil Science 119: 242-249.

Ghilarov, M.S., 1963. On the interrelations between soil dwelling invertebrates and soil micro-organisms. Pgs 255-265 in Soil Organisms, edited by J. Doeksen, J. Van der Drift, North Holland Publishing Company.

Hendrix, P.F., D.A.Jr. Crossley, J.M. Blair, and D.C. Coleman, 1990. Soil biota as components of sustainable agroecosystems. Pgs 637-654 In Sustainable Agricultural Systems, C. Edwards, R. Lal, P. Madden, R.H. Miller, G. House, Editors. Soil and Water Conservation Society, Ankney, Iowa, U.S.A.

Hill, M.O., 1973. Diversity and eveness: a unifying notation and its consequences. Ecology 54: 427-432.

House, G.J., All, J.N., 1981. Carabid beetles in soybean agroecosystems. Environmental Entomology 10: 194-196.

Kort, J., 1988. Benefits of windbreaks to field and forage crops. Agriculture, Ecosystems and Environment 22/23: 165-170.

Krebs, C.J., 1985. Ecology: The experimental analysis of distribution and abundance. 3rd edition. Harper and Row Publishers, New York.

Krysan, J.L., Foster, D.E., Branson, T.F., Ostlie, K.R., Craqnshaw, W.S., 1986. Two years before the hatch: Rootworms adapt to crop rotation. Bulletin of the Entomological Society of America 32: 250-253.

Lal, R., 1988. Effects of macrofauna on soil properties in tropical ecosystems. Agriculture, Ecosystems and Environment 24: 101-116.

Lys, J.A., Nentwig, W., 1991. Surface activity of carabids inhabiting cereal fields: Seasonal phenology and the influence of farming operations on five abundant species. Pedobiologia 35: 129-138.

MacKay, A.D., Kladivko, E.J., 1985. Earthworms and rate of breakdown of soybean and maize residues in soil. Soil Biology and Biochemistry 17: 851-857.

Miko, L., Tesliarova, Z., Grejtovsky, A., Dunay, G., 1989. The influence of poplar windbreaks on selected biological characteristics of heavy soils in the East-Slovakien lowland. Ecology (CSSR) 8: 275-285.

Nazzi, F., M.G. Paoletti, and G.G. Lorenzoni, 1989. Soil invertebrate dynamics of soybean agro-ecosystems encircled by hedgerows or not in Fruili, Italy. First data. Agriculture, Ecosystems and Environment 27: 163-176.

Neave, P.R., 1992. The response of soil microflora and fauna to spring plowing of old field and zerotill soils. M.Sc. thesis, University of Guelph, Guelph, Ont.

Pasek, J.E., 1988. Influence of wind and windbreaks on local dispersal of insects. Agriculture, Ecosystems and Environment 22/23: 539-554.

Pollard, E., 1971. Hedges. VI. Habitat diversity and crop pests: a study of Brevicoryne brassicae and its syrphid predators. Journal of Applied Ecology 8: 751-780.

Raw, F., 1959. Estimating earthworm populations by using formalin. Nature 184: 1661-1662.

Reichert, S.E., Lockley, T., 1984. Spiders as biological control agents. Annual Review of Entomology 29: 299-320.

Reynolds, J.W., 1977. The earthworms (Lumbricidae and Sparganophilidae) of Ontario. Royal Ontario Museum Life Sciences Miscellaneous Publications.

Shaw, C., Pawluk, S., 1986. The development of soil structure by Octolasion tyrtaeum, Aporrectodea turgida, and Lumbricus terrestris and its relation to the carbon budgets of three artificial soils. Pedobiologia 29: 377-389.

Shelley, R.M., 1988. The millipedes of Eastern Canada (Arthropoda: Diplopoda). Canadian Journal of Zoology 66: 1638-1663.

Shipitalo, M.J., Protz, R., 1987. Comparison of morphology and porosity of a soil under conventional and zerotillage. Canadian Journal of Soil Science 67: 445-456.

Southwood, T.R.E., 1987. Ecological methods: with particular reference to the study of insect populations. Chapman and Hall, New York.

Thiele, H.U., 1977. Carabid beetles in their environments. Springer-Verlag, New York.

Van Emden, H.F., 1965. The role of uncultivated land in the biology of crop pests and beneficial insects. Scientific Horticulture 17: 121-136.

Villee, C.A., Solomon, E.P., Davis, P.W., 1985. Biology. Saunders College Publishing, Toronto.

Vimmerstedt, J.P., Finney, J.H., 1973. Impact of earthworm introduction on litter burial and nutrient distribution in Ohio strip-mine spoil banks. Soil Science Society of America Proceedings 37: 388-391.

Wallin, H., 1985. Spatial and temporal distribution of some abundant carabid beetles (Coleoptera: Carabidae) in cereal fields and adjacent habitats. Pedobiologia 28: 19-34.

Zachmann, J.E., Linden, D.R., 1989. Earthworm effects on corn residue breakdown and infiltration. Soil Science Society of America Journal 53: 1846-1849.

Table 1. Occurrence of cryptozoic invertebrates in barley- and no-residue corn fields, and fall- and spring-plowed soybean fields at distances <8 m, and >8 m from a woodlot, on the first sample date.

Taxon	Presence (X) or absence (-)							
	Barley-res. corn		No-residue corn		Fall-plowed soybeans		Spring-plowed soybeans	
	<8m	>8m	<8m	>8m	<8m	>8m	<8m	>8m
slugs	X	-	X	-	X	-	X	-
land snail	X	-	X	-	-	-	X	-
earthworm	X	X	-	-	X	-	X	X
sowbugs	X	X	X	X	X	-	X	X
Entomobryinae	-	-	X	-	-	-	-	-
Sminthurinae	X	-	-	-	-	-	X	-
grasshoppers	X	X	-	-	X	X	X	X
crickets	X	X	X	X	X	X	X	X
leafhopper	X	X	X	X	X	X	-	X
damsel bug	X	-	-	X	-	-	-	-
aphid	X	X	X	X	-	-	-	X
Coleoptera A	-	-	-	-	X	X	X	X
beetle larvae	X	X	X	-	X	-	X	X
Staphylinidae A	X	X	X	-	X	X	X	X
Staphylinidae B	-	-	X	-	X	-	X	-
Nitidulidae	X	X	X	X	X	X	X	-
ground beetle A	X	X	X	X	X	X	X	X
ground beetle B	X	X	X	X	X	X	-	X
ground beetle C	X	-	X	X	-	X	-	-
ground beetle D	-	-	X	X	X	-	-	-
ground beetle E	X	-	X	-	-	-	X	-
ground beetle F	X	X	-	X	X	X	X	X
ground beetle G	-	-	-	-	X	X	X	X
ground beetle H	-	-	X	-	-	-	-	-
ground beetle I	X	-	-	-	-	-	-	-
ground beetle J	-	-	-	-	X	X	X	X
ground beetle K	-	-	-	-	-	-	-	X
Coccinellidae	X	X	X	X	X	X	-	X
Cantharidae	X	-	X	X	X	-	-	-
bombadier beetle	-	-	-	-	-	X	-	X
Elateridae	-	-	-	-	X	-	X	-
weevil	X	-	X	-	X	X	-	X
Scarabaeidae	X	X	X	-	-	-	-	X
Lepidoptera A	X	-	-	-	-	X	X	X
Lepidoptera B	-	-	X	-	-	-	X	-
hornworm	-	-	-	-	-	-	X	-
Diptera A	-	-	-	-	X	-	-	-

Table 1 continued

Diptera B	-	-	-	-	-	X	-	-
Diptera C	-	-	-	-	X	-	X	X
Diptera D	-	-	-	-	X	-	-	-
Sciaridae	-	X	-	X	X	-	X	-
Tipulidae	X	-	-	-	-	X	-	X
Phoridae	X	X	X	-	X	-	-	X
Syrphidae	-	-	X	-	-	-	-	-
Empididae	X	-	-	-	-	-	X	-
Calliphoridae	-	-	-	-	-	-	X	X
Anthomyiidae	X	X	X	X	X	X	X	X
Drosophilidae	X	-	-	-	-	-	-	-
Pipinculidae	-	-	-	-	-	X	-	-
ants	X	X	X	X	X	X	X	X
Braconidae	X	X	X	X	X	X	-	X
dauber	-	-	-	-	-	-	X	-
Apidae	-	-	-	-	X	X	-	-
wolf spider	X	X	X	-	X	X	X	X
orb spider	X	X	-	-	-	-	-	-
harvestmen	X	X	X	X	X	X	X	X
Blanilius	X	-	X	-	X	-	X	-
Scytonotus	X	-	-	-	-	-	X	-
velvet mite	-	-	-	-	-	-	X	-
toad	-	-	-	-	X	-	X	-
Total -	36	22	30	18	34	26	34	30

Table 2. Occurrence of cryptozoic invertebrates in barley- and no-residue corn fields, and fall- and spring-plowed soybean fields at distances <8m, and >8m from a woodlot, on the fifth sample date.

Taxon	Presence (X) or absence (-)							
	Barley-res. corn		No-residue corn		Fall-plowed soybeans		Spring-plowed soybeans	
	<8m	>8m	<8m	>8m	<8m	>8m	<8m	>8m
slugs	X	X	X	X	X	X	X	X
land snail	X	-	X	-	-	-	-	-
earthworms	X	X	X	X	-	X	-	X
sowbugs	X	X	X	-	X	-	X	X
grasshopper	-	-	-	-	X	X	X	X
cricket	X	X	X	-	X	X	X	X
earwig	X	X	-	-	-	X	X	X
leafhopper	X	X	X	X	X	X	X	X
aphids	-	-	-	X	-	-	-	-
Hemiptera A	-	-	-	-	-	-	-	X
Nabidae	X	-	X	-	X	X	X	-
Coleoptera A	-	-	X	-	-	-	-	-
Coleoptera B	X	-	X	-	-	-	-	-
beetle larvae	X	-	-	-	-	-	-	-
StaphylinidaeA	-	X	X	X	X	X	X	X
Staphy. B	X	X	X	-	X	X	X	X
ground beetleA	-	-	-	-	X	X	X	X
ground beetleB	X	X	X	X	X	X	X	X
ground beetleD	X	X	X	-	X	X	X	-
ground beetleF	X	-	-	-	X	X	X	X
ground beetleG	X	X	X	X	-	X	-	-
ground beetleJ	-	-	-	X	-	X	-	-
Nitidulidae	-	-	-	X	X	X	-	-
Coccinellidae	-	-	X	-	X	X	X	X
Cantharidae	-	-	X	-	-	-	-	-
weevil	-	X	-	-	X	X	X	X
Lepidoptera A	-	-	-	-	X	-	-	-
Lepidoptera B	-	-	X	-	-	-	-	X
Diptera D	-	X	X	-	X	X	-	-
Sciaridae	X	X	X	X	-	X	X	X
Phoridae	-	X	X	X	-	-	-	X
Syrphidae	-	-	X	-	-	-	-	-
Empididae	-	-	-	-	-	-	X	-
Anthomyiidae	X	X	X	X	X	X	X	X
Calliphoridae	-	-	-	-	-	-	X	-
robber fly	-	-	-	-	-	-	X	-
Drosophilidae	-	-	-	-	X	X	X	-

Table 2 continued

ants	X	X	X	X	X	X	X	X
Braconidae	X	-	X	X	X	X	X	X
Apidae	-	-	-	-	X	X	-	-
Lithobiomorpha	-	-	-	-	X	-	-	-
harvestmen	X	X	X	X	X	X	X	X
spider	-	-	-	X	-	-	-	-
wolf spider	X	-	-	-	-	-	-	-
Blanilius	X	X	X	X	X	X	X	X
Scytonotus	X	-	X	-	-	-	X	-
Total -	23	20	28	17	26	27	25	25

Table 3. Intercepts and their standard errors for cryptozoic abundance, richness and eveness, and earthworm number and mass in the four cropping systems.

Variable	Intercept in the cropping system				
	Barley-residue corn		No-residue corn	Fall-plowed soybeans	Spring-plowed soybeans
Cryptozoic abundance	4.652 (0.398)		4.809 (0.398)	4.827 ** (0.375)	6.431 (0.289)
Cryptozoic richness	7.011 (0.630)		6.423 (0.630)	6.548 ** (0.594)	8.274 (0.425)
Cryptozoic eveness	0.796 (0.030)		0.838 (0.030)	0.812 ** (0.030)	0.718 (0.020)
Number of carabids	1.577 (0.258)		1.289 (0.259)	0.972 (0.243)	0.944 (0.173)
Richness of carabids	1.477 (0.236)		1.665 (0.237)	1.631 (0.223)	1.431 (0.158)
Number of earthworms	4.586 (3.102)	**	23.36 (3.102)	-	5.230 (2.624)
Mass of earthworms	9.676 (3.365)	**	18.15 (3.365)	-	1.230 (2.673)

** indicates a significant difference between intercepts

Table 4. List of arthropods captured in intercept traps in the barley-residue corn cropping system, at 0, 20 and 40 m from the woodlot.

Harvestmen	(Order Phalangida)
Sowbug	(Order Isopoda)
Leafhopper	(Family Cicadellidae)
Aphid	(F. Aphididae)
Damsel bug	(F. Nabidae)
Rove beetle	(F. Staphylinidae)
Ground beetle	(F. Carabidae)
Soldier beetle	(F. Cantharidae)
Sap beetle	(F. Nitidulidae)
Ladybird beetle	(F. Coccinellidae)
Noctuidae caterpillar	(Order Lepidoptera)
Dark winged fungus gnat	(F. Sciaridae)
Deer fly	(F. Tabanidae)
Anthomyiidae Blow fly	(F. Calliphoridae)
Green bottle fly	(F. Calliphoridae)
Ant	(F. Formicidae)
Parasitic wasp	(F. Braconidae)
bee	(F. Apidae)

Table 5. Water content (%) at different distances from a woodlot in the different cropping systems, on October 15-18.

Cropping system	Distance from woodlot				
	0m	7.5m	15m	30m	50m
Barley-res. corn	22.1	25.3	26.3	28.3	24.2
No-residue corn	34.1	31.3	31.2	28.5	27.9
Spring-plowed soybeans	22.1	25.3	26.3	28.3	24.2

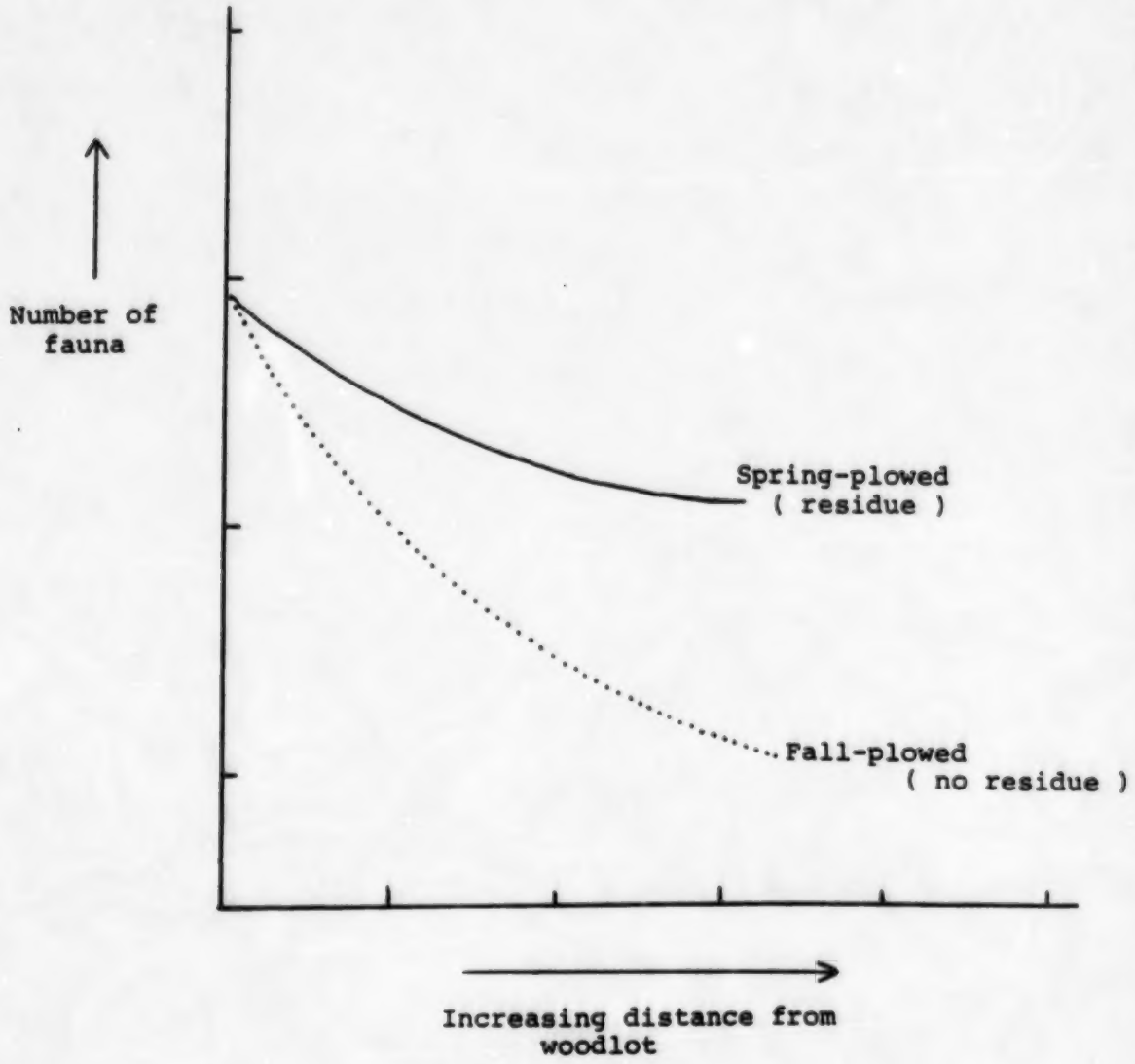

Figure 1. Hypothetical number of fauna found in soils with, and soils without crop residue, at different distances from a woodlot. Rate of decrease (slope) is less in the soil with crop residue.

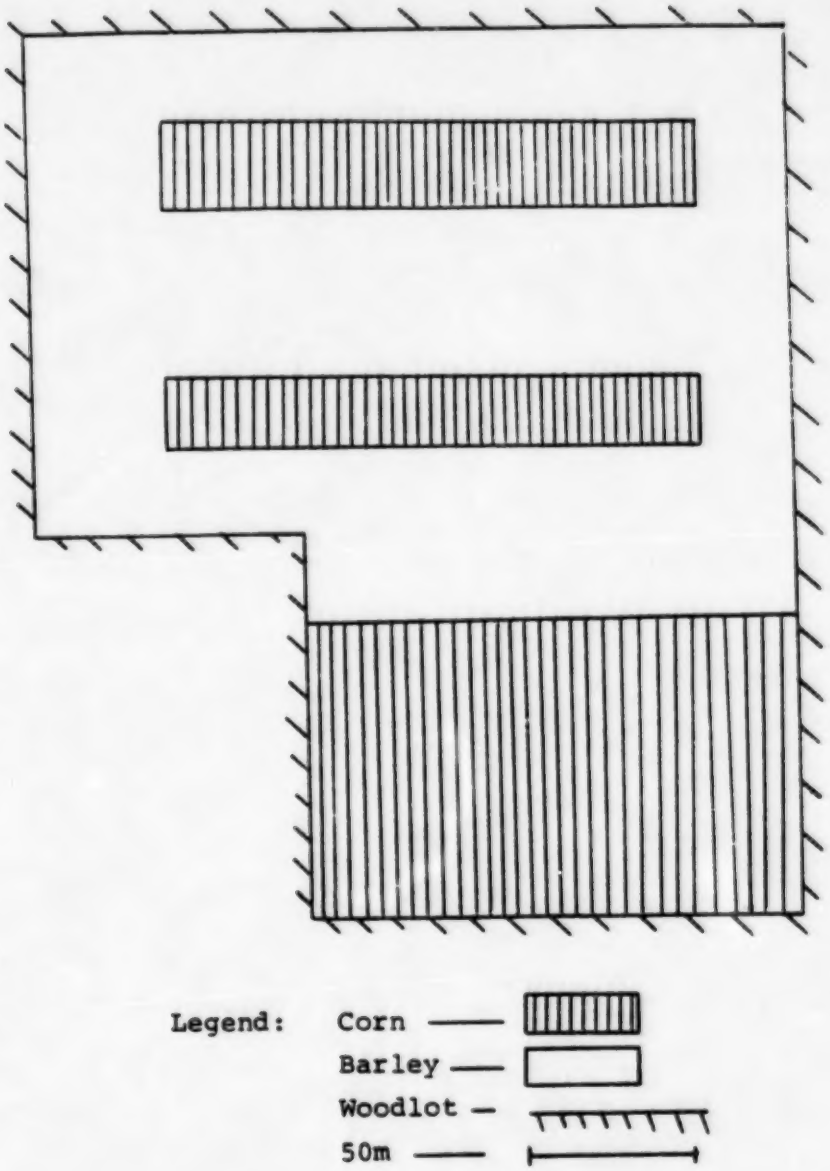

Figure 2. Pattern of crops grown in a zerotillage field south of Mount Forest, Ontario, in 1990.

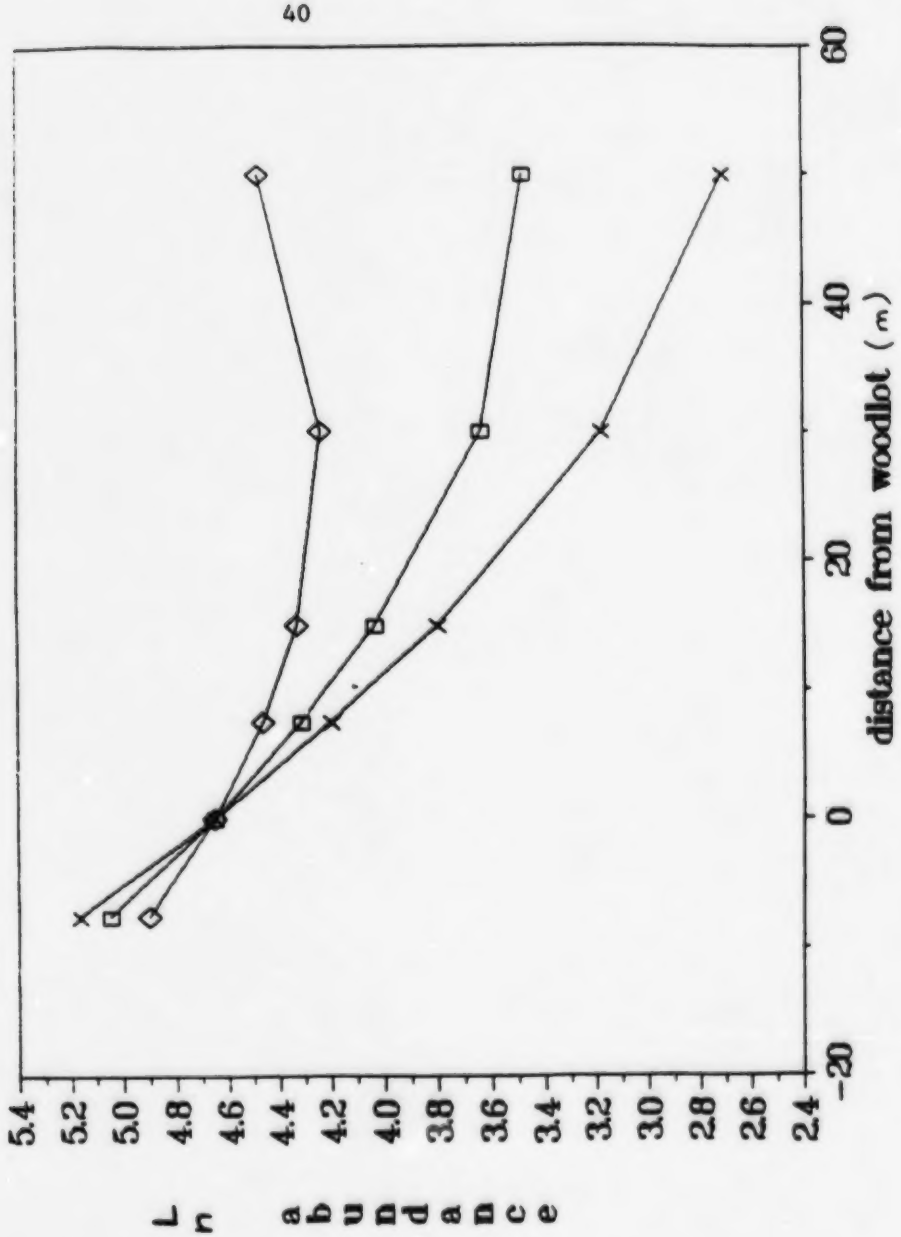

Figure 3. Decrease in cryptozoic abundance in the barley-residue corn cropping system at three sample dates, with increasing distance into the field. Distance 0 represents the edge of the field, negative values are within the woodlot, and positive values are within the field. This applies to all successive figures.

Legend: ◇ August 2-9, □ August 30 - September 6, × October 8-16.

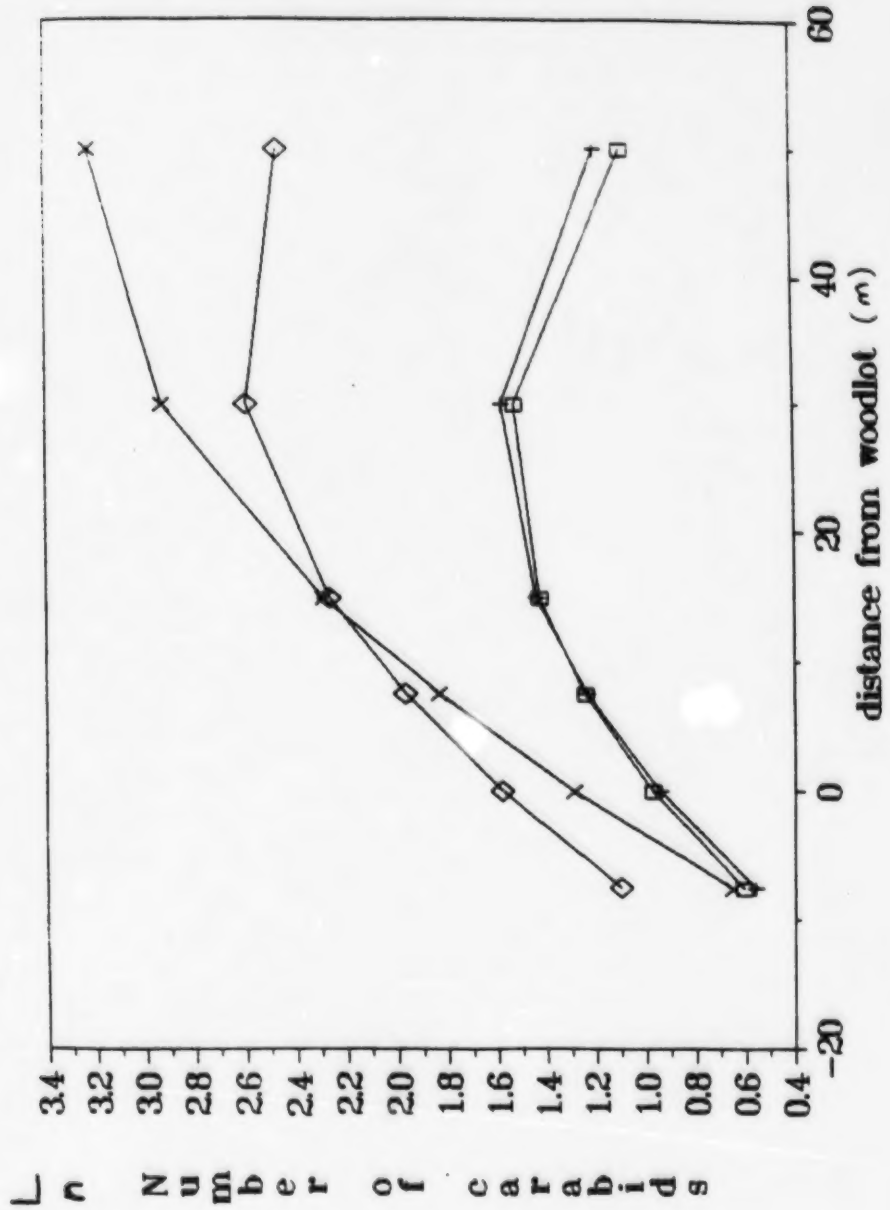

Figure 4. Increase in number of carabids with increasing distance into the field, for the four cropping systems.

Legend: ◇ Barley residue corn field, × No-residue corn field, □ Fall plowed soybean field, + Spring plowed soybean field.

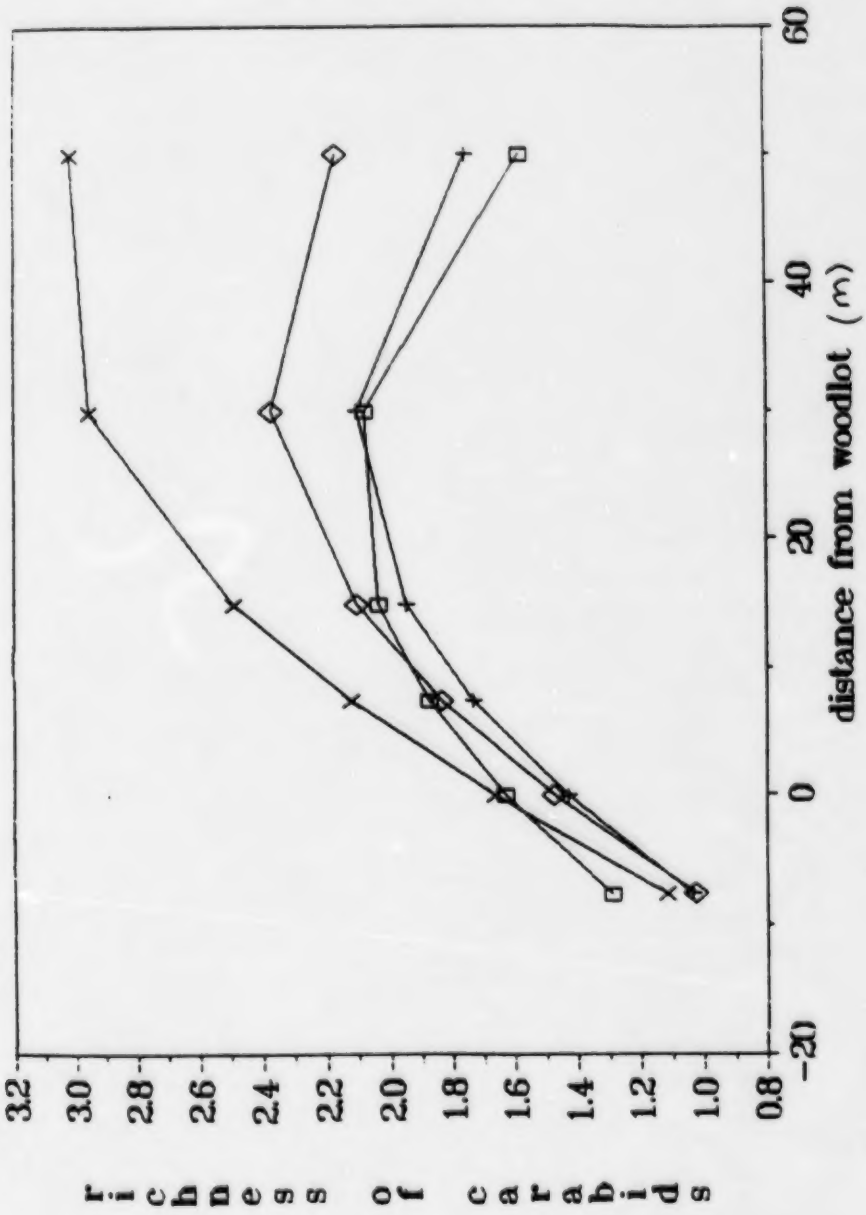

Figure 5. Increase in carabid richness with increasing distance into the field, for the four cropping systems.

Legend: ◇ Barley residue corn field, × No residue corn field, □ Fall plowed soybean field, + Spring plowed soybean field.

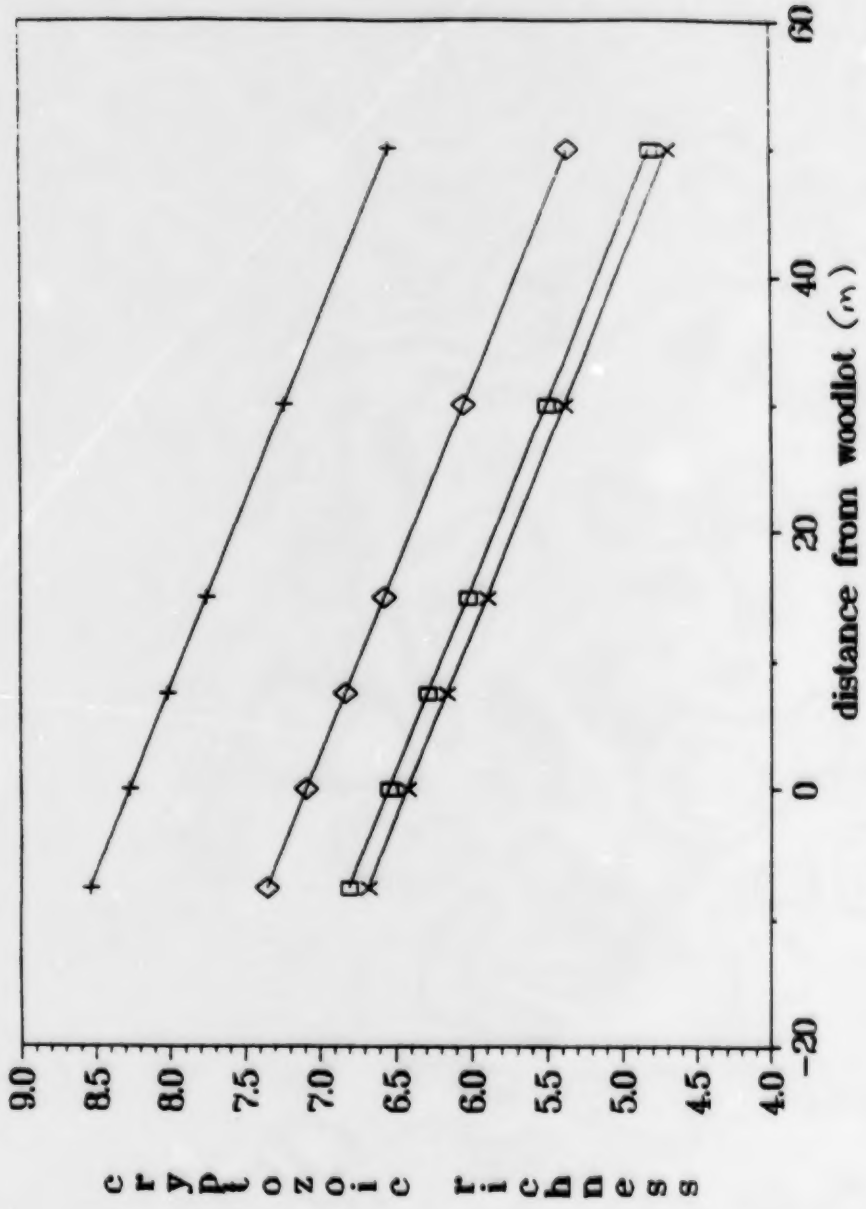

Figure 6. Decrease in cryptozoic richness in the four cropping systems with increasing distance into the field.

Legend: ◇ Barley residue corn field, × No residue corn field, □ Fall plowed soybean field, + Spring plowed soybean field.

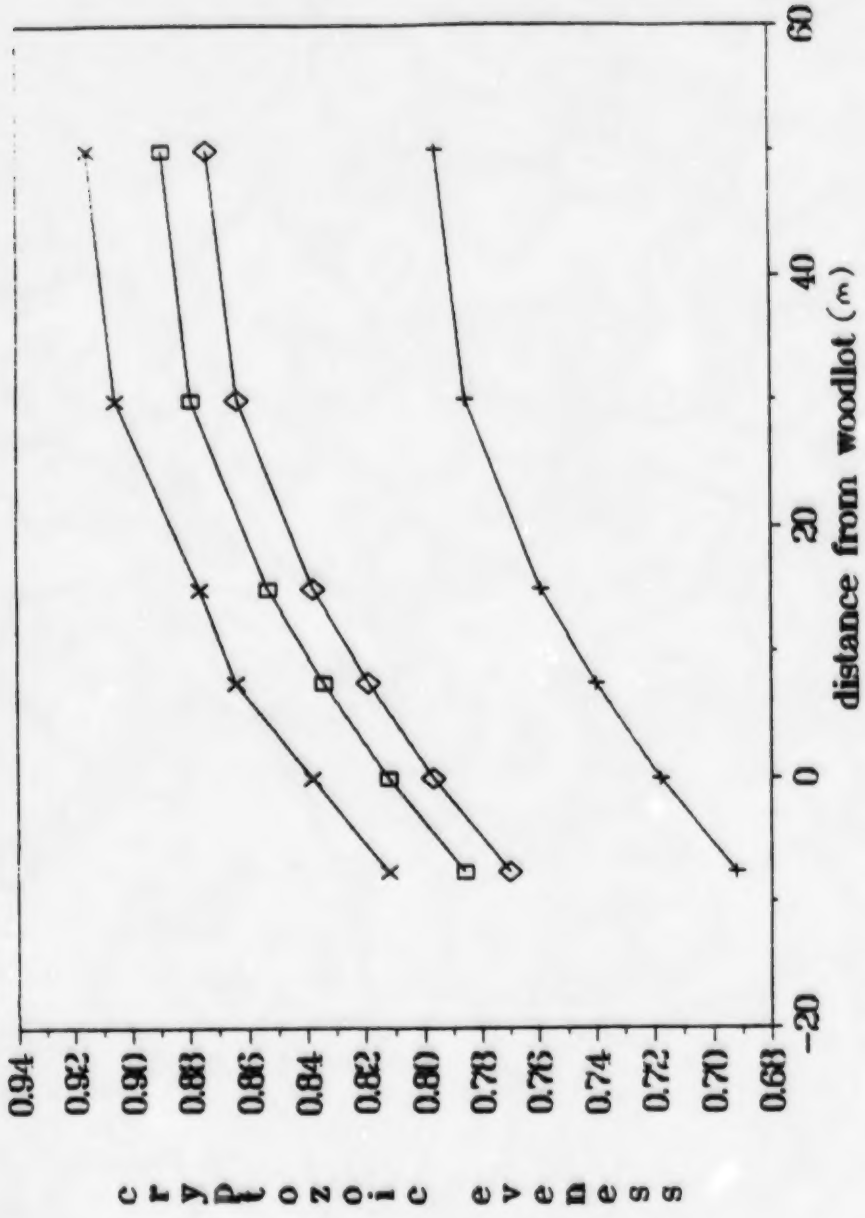

Figure 7. Increase in the eveness of the cryptozoic community in the four cropping systems with increasing distance into the field.

Legend: ◇ Barley residue corn field, × No residue corn field, □ Fall plowed soybean field, + Spring plowed soybean field.

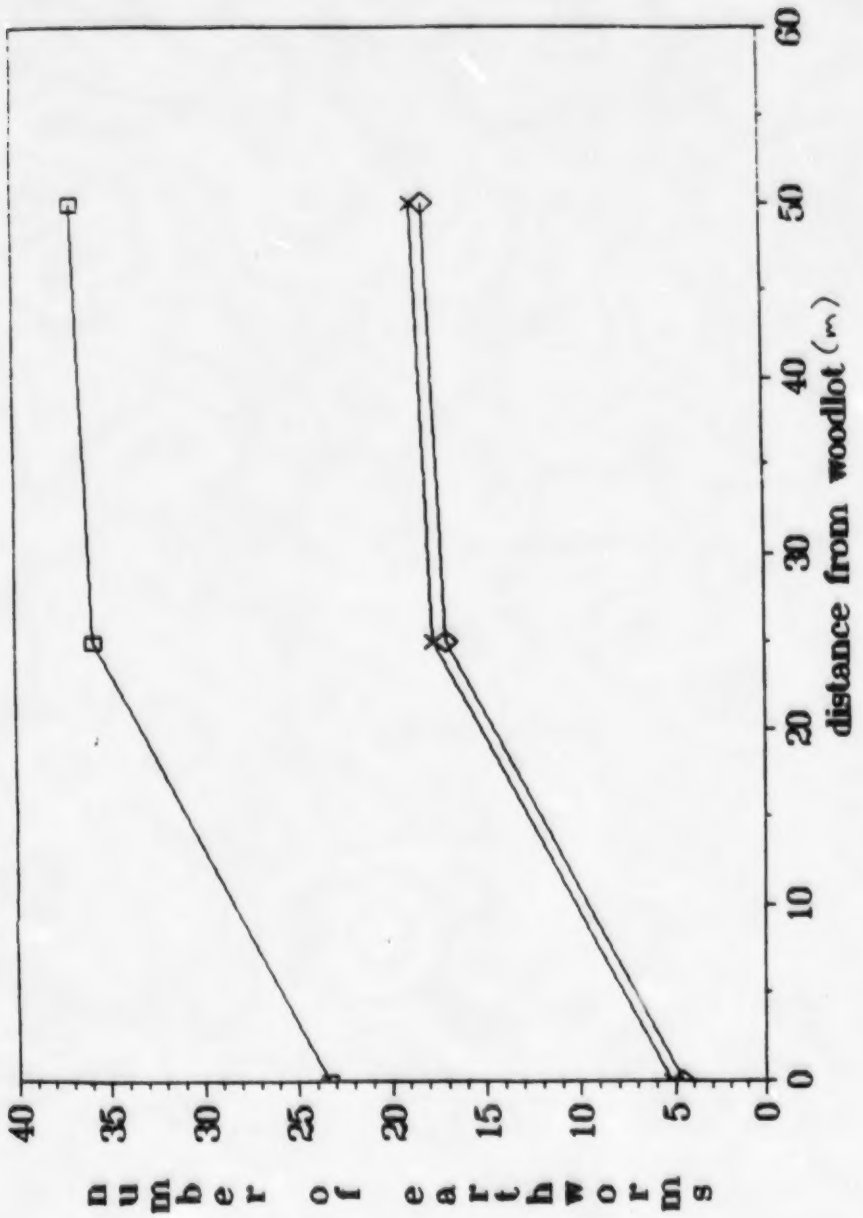

Figure 8. Increase in the number of earthworms in three cropping systems with increasing distance into the field.

Legend: ◇ Barley residue corn field, □ No residue corn field, × Spring plowed soybean field.

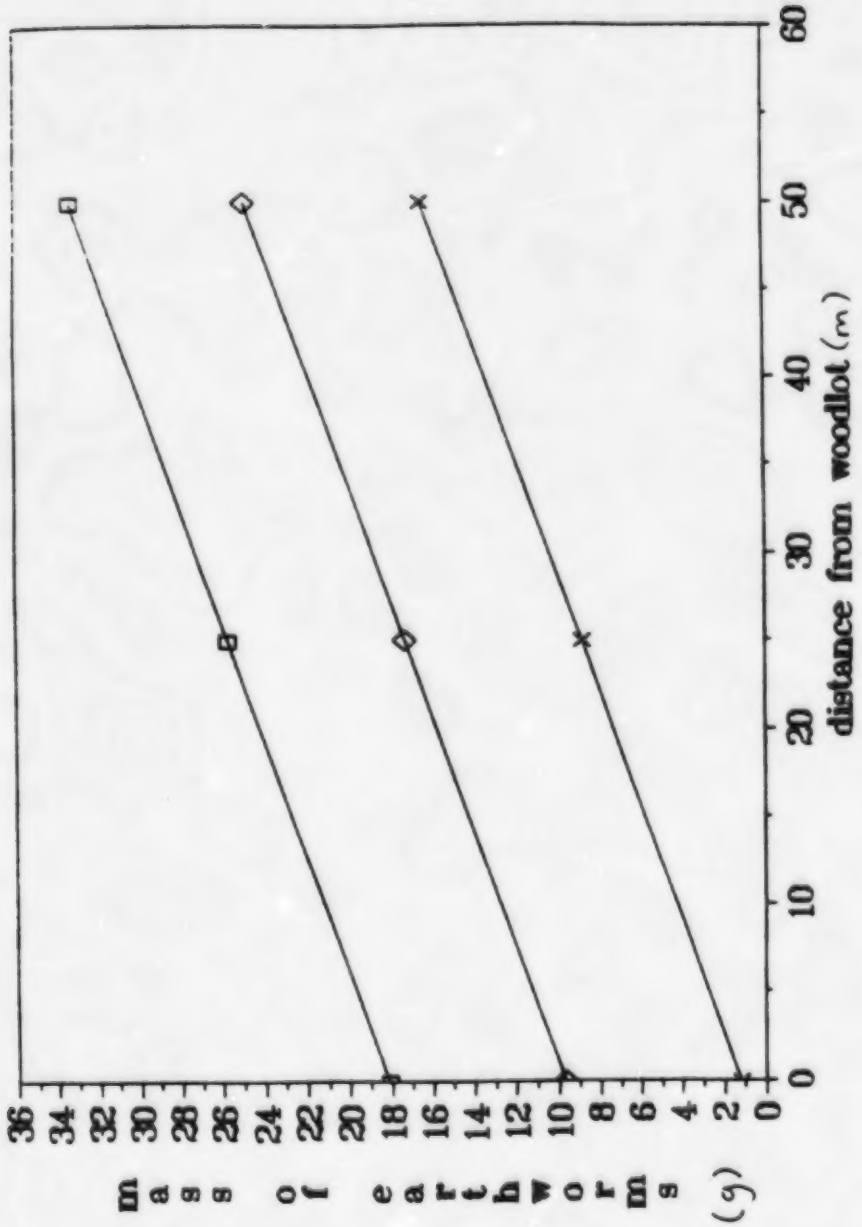

Figure 9. Increase in the mass of earthworms in three cropping systems with increasing distance into the field.

Legend: ◇ Barley residue corn field, □ No residue corn field, × Spring plowed soybean field.

Appendix Systematic list of animals considered in this study, to the lowest level of identification.

The Phylum and Class level of classification was taken from Villee, Solomon and Davis (1985). The Philomycidae classification is from Burch (1962), and the Lumbricidae and Sparganophilidae classification is from Reynolds (1977). Diplopoda classification is from Shelley (1988), and all other orders, suborders, and families were from the classification of Borror and Delong (1964).

Kingdom Animalia

- Phylum Mollusca
  - Class Gastropoda
    - Family Philomycidae - slugs
- Phylum Annelida
  - Class Oligochaeta
    - Family Lumbricidae - earthworms
    - Family Sparganophilidae - earthworms
- Phylum Arthropoda
  - Subphylum Chelicerata
    - Class Arachnida
      - Order Phalangida - harvestmen
      - Order Acarina - mites
        - velvet mite
      - Order Araneida - spiders
  - Subphylum Crustacea
    - Class Crustacea
      - Order Isopoda - sowbugs
  - Subphylum Urinamia
    - Class Chilopoda - centipedes
      - Order Lithobiomorpha
    - Class Diplopoda - millipedes
      - Order Polydesmida - *Scytonotus granulatus*
      - Order Julida - *Archiborioiulus pallidus*
    - Class Insecta
      - Subclass Apterygota
        - Order Collembola - springtails
          - Family Sminthuridae
          - Family Entomobryinae
      - Subclass Pterygota
        - Order Orthoptera
          - Family Acrididae - grasshoppers
          - Family Gryllidae - crickets
        - Order Dermaptera - earwigs
        - Order Hemiptera
          - Family Nabidae - damsel bugs
        - Order Homoptera

Family Cicadellidae - leafhoppers
Family Aphididae - aphids
Order Coleoptera
Family Staphylinidae - rove beetles
Family Carabidae - carabid beetles

Family Cantharidae - soldier beetles
Family Elateridae - click beetles
Family Nitidulidae - sap beetles
Family Coccinellidae - ladybird beetles
Family Meloidae - bombardier beetles
Family Curculionidae - snout beetles
Family Scarabaeidae - scarab beetles
Order Lepidoptera -butterflies and moths
Family Sphingidae - hornworms
Family Noctuidae
Order Diptera
Family Tipulidae- crane flies
Family Mycetophilidae - fungus gnats
Family Sciaridae - dark winged fungus gnats
Family Empididae - dance flies
Family Phoridae - humpbacked flies
Family Syrphidae - bee flies
Family Tabanidae - deer flies
Family Asilidae-robber flies
Family Calliphoridae - blow flies
Family Anthomyiidae
Family Drosophilidae
Family Pipinculidae
Order Hymenoptera
Family Braconidae - parasitic wasps

Family Larrinae -
mud dauber
Family Formicidae - ants
Family Apidae -bees